



PROTOCOL FOR BIOCHAR USE IN INDIAN AGRICULTURE



ICAR-Indian Institute of Soil Science

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Protocol for Biochar Use in Indian Agriculture

Introduction

The term biochar refers to black carbon formed by the slow pyrolysis of biomass under oxygen-free or stress environment so that it does not completely combust. Charcoal is a good example of biochar produced from woody biomass. The use of biochar as soil amendments is proposed as panacea for mitigating climate change along with improving soil productivity. Such partially burnt products, may act as an important long-term carbon sink. Biochar contains high concentrations of recalcitrant carbon thereby sequestering carbon for a long period of time (Glaser et al., 2002). High fertility associated with the anthropogenic soils i.e. terra preta has been related to the high content of organic carbon in the form of char (Glaser et al., 2001).

The use of biochar in agriculture is not new. Farmers have been using it unknowingly for enhancing the production of agricultural crops since long. One such example is the slash and burn cultivation, which is still being practiced in some part of north-eastern India. Biochar can be used to sequester carbon on centurial or even millennial time scales. In the natural carbon cycle, plant matter decomposes rapidly after completion of life cycle and emits carbon dioxide back to the atmosphere. The overall natural cycle is carbon neutral. About 85-95% of plant biomass carbon after decomposition returned back to the atmosphere, whereas if we make biochar from the same biomass atleast 50% of the total carbon is captured permanently (Jha et al, 2010). Biochar thus removes circulating carbon dioxide from the atmosphere and stores it in virtually permanent soil carbon pools, making it a carbon-negative process.

According to different estimates, 72-127 Mt of crop residues are burnt on-farm in India (Pathak et al., 2006; Pathak et al., 2010). Open field burning of crop residues is perceived as an age old practice to boost soil fertility in terms of P and K, but often leads to a loss of other nutrients (e.g. N and S), organic matter and microbial activity required for maintaining better



soil health. Burning this crop residues also releases black carbon, a type of fine particulate matter formed from incomplete combustion. These particles are then funneled by air currents from rural farms to nearby urban area. Hence, conversion of organic waste to produce biochar using the pyrolysis process is one viable option that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil quality (Srinivasarao et al., 2012 & 2013).

Feedstocks for Preparation of Biochar

Biochar obtained by slow pyrolysis from biomass waste has a primary goal of soil improvement. The nature and quality of biochar produced depends on the type of feedstock used. Most of biological sources can be conveniently used for biochar production however there are few limitations with respect to the type of feed stock being used. The biochar formed should not contain more than 2% by dry weight of any contaminants (Brinton 2000). Even FYM/other manures/ municipal solid waste may be used for making biochar provided it should not contain any hazardous materials. It is the manufacturer's responsibility to ensure that biochar feedstock materials are free of hazardous materials. In India, apart from other biological sources, there is 234.5 million tonnes of surplus crop residues that are either burnt or even supplied to power generation units (Moonmoon Hiloidhar et al. 2014).

Production Methodologies

Biochar is the charred biomass produced by slow pyrolysis in which organic material is heated under controlled temperatures (300-500°C) in the absence of oxygen. The biochar produced should have high carbon content ($> 60\% \text{ C}$; H:C molar ratio should not exceed 0.7). Various pyrolysis technologies are commercially available that yield different proportions of biochar depending upon the residues used for production under varying operating conditions.

Biochar production protocols in India are yet to be standardized. A low cost portable biochar kiln with proper design and operational process can be considered as an economically viable option for rainfed areas in developing countries for efficient recycling of unused and excess crop residues (Venkatesh et al 2018). There are different ways to make biochar. It involves heating of biomass with little or no oxygen to drive off volatile gases. The carbonization process undergoes three steps viz. removal of moisture and some volatile compounds which are followed by conversion of unreacted residues to volatiles, gasses and biochar, and finally formation of recalcitrant material called biochar through



slow chemical rearrangement. Various pyrolysis technologies produce different proportion of biochar and other by-products, such as bio-oil and syngas. The gaseous bio-energy products may be used to generate electricity. Bio-oil may be used directly for low-grade heating applications as well as a diesel substitute after suitable treatment.

In India low cost technologies have been developed by some institutions having minimal control over temperature and time parameters. Biochar can be successfully made using these methods provided H:C molar ratio of final product is <0.7 . Some of the commonly used methods in India are described as under:

Heaping and charring

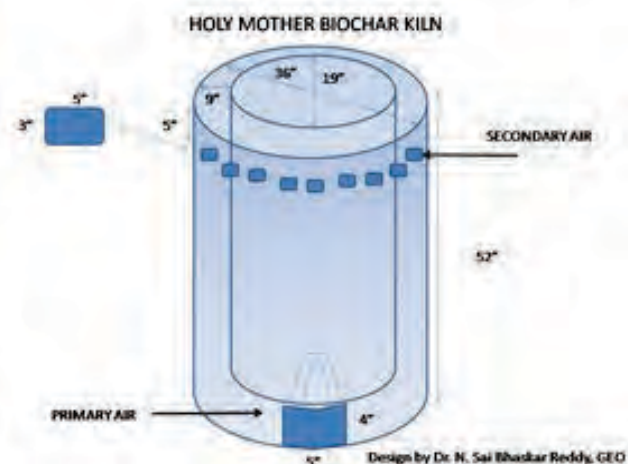
In heap method (Tamilnadu) biomass such as wood lopping, small wood logs, twigs, woody crop residues etc is piled up to a height of about three to four feet and is covered with mud paste. Vents are opened starting from the top and working downwards on drying of mud paste. The heap is set at fire from one end and let to smoke for a considerable time period usually in few days to week. Biochar is formed under oxygen stress conditions but there is no perfect control over temperature and air.



Biochar kiln

a) Holy Mother Biochar Kiln developed by Sarada Matt, Almora, Uttarakhand, India in which bricks and clay are used in the construction. The biomass is added continuously as the fire continues. Air is allowed to flow from bottom as long as biomass is added continuously while burning. As the biomass reaches the level just below the secondary air vents, further addition of biomass is stopped and then the bottom vent is also closed. After some time, water is sprinkled to extinguish the fire. The biochar is collected after some time. Biochar is formed under oxygen stress conditions but there is no perfect control over temperature.





Biochar kiln in Almora, UK (Source: <https://biocharkiln.blogspot.com/>)

b) ICAR-CIAE biochar kiln: ICAR-CIAE has also developed different designs of biochar kilns for preparation of biochar. These designs vary with a small capacity of about 500 g to as high as 5 -10 kg biochar.



Drum method

Various forms of drum have been developed by different organizations. Some have developed them in horizontal and others have made it as vertical equipment. Also some require external heating, the other may need initial sparking for burning. There is hardly any control over the temperature and air supply. Also the pyrolysed biomass may not be uniform. The ash content in the biochar is also high. Following are some of the drums used.



Standard biochar production units

- Systematic biochar production has been attempted at few locations. ICAR-Research Complex for NEH Region at Barapani established pyrolysis plant that has a capacity to use 300 kg of feedstock. Similarly ICAR-CIAE Bhopal has designed a biochar plant for a smaller quantity of biochar production. It does not require any initial ignition. Only electric heaters are installed for pyrolysis of the biomass. In this kiln there is control over temperature. The smoke is also disposed off safely.



Biomass pyrolyser at ICAR Research Complex for NEH region, Barapani



Biomass pyrolyser developed at ICAR-CIAE, Bhopal

- MPUAT Udaipur has developed a batch type continuous torrefaction unit using a suitable gear motor. It can torrefy about 15-20 kg of crop residues per hour. There is generation of considerable amount of gases also (Anonymous, Annual report CIAE 2017-18). MPUAT has also developed system of continuous screw type biochar production of 20 kg d⁻¹ capacity. Using groundnut shell it can produce 6 kg biochar per hour, which has calorific value of 5935 kcal/kg which is 58.3% higher than raw material.



Best Management Practices for Biochar Production (*Adapted from IBI*)

Local requirements and regulations for the operation of biochar production facilities should be followed. Where applicable, biochar production must comply with local and international regulatory requirements and treaties that govern thermal processes, the production of volatile and particulate emissions, and the transport of goods. The biochar manufacturer must adhere to relevant local and international regulatory compliance along with following BMPs:

- 1) A biochar manufacturer should provide a relevant material safety data sheet (MSDS) for the final output of its biochar production process.
- 2) Biochar should be tested to address the potential for self-heating and flammability during storage and transport. Documentation of the results of this testing should be appended to the MSDS.
- 3) To minimize the effects of weathering which can significantly alter the material properties of biochar after it has been tested, biochar should be stored indoors in a protected location. If stored outdoors, biochar should be covered with a tarpaulin or other material to protect it from precipitation events.

Biochar Standards

The IBI has suggested three categories of tests for biochar materials that may also be followed in India.

Test Category A (basic utility property (Table 1)	Test Category B (Assessment of toxicants) (Table 2)	Test Category C and D (Table 3 and Table 4)
Compulsory for all biochar	Compulsory for all biochar	Optional for all biochar

Test Category A : All biochars must be tested for basic utility properties and meet the criteria specified under Test Category A, as shown in Table 1 (*Adapted from IBI*).

Table 1: Test Category A Parameters, Criteria, and Test Method (Basic utility properties)

Parameter	Criteria	Unit	Test Method
Moisture	Declaration	% of total mass, dry basis	Standard Test Method for gravimetric moisture estimation (Specify measurement date with respect to time from production)
Organic Carbon (C_{org})	10% Minimum Class 1: $\geq 60\%$ Class 2: $\geq 30\%$ and $< 60\%$ Class 3: $\geq 10\%$ and $< 30\%$	% of total mass, dry basis	Total C and H analysis by dry combustion-elemental analyzer. Inorganic C analysis by determination of CO_2 -C content with 1N HCl. Organic C = Total C- Inorganic C.
H: C_{org}	0.7 Maximum	Molar ratio	
Total Ash	Declaration	% of total mass, dry basis	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal.
Total Nitrogen	Declaration	% of total mass, dry basis	Dry combustion-elemental analyzer following the same procedure for total C and H above.
pH	Declaration	-	pH analysis procedures of TMECC (2001) using modified dilution of 1:20 biochar:deionized H_2O (w:v) and equilibration at 90 minutes on the shaker, according to Rajkovich et al. (2011).
Electrical Conductivity	Declaration	dS/m	EC analysis procedures of TMECC (2001) using modified dilution of 1:20 biochar:deionized H_2O (w:v) and equilibration at 90 minutes on the shaker, according to Rajkovich et al. (2011).



Parameter	Criteria	Unit	Test Method
Liming (if pH is above 7)	Declaration	% CaCO_3	AOAC 955.01 potentiometric titration on “as received “ (i.e., wet) samples. Use dry weight to calculate % CaCO_3 and report “per dry sample weight”.
Particle size distribution	Declaration	% < 0.2 mm; % 0.2-2.0 mm % > 20mm;	Progressive dry sieving with 200 μm , 2,000 μm and 20,000 μm sieves, as outlined in ASTM D5158-98 - Method for activated carbon.

Test Category B

Toxicant Assessment In addition to Test Category A thresholds and declarations, all biochar materials must meet the soil toxicity assessment thresholds as outlined in Table 2 below. Biochar made from processed feedstocks may carry additional risks from the potential presence of toxicants in the feedstock. Biochar toxicity assessment reporting follows commonly identified soil toxicity and chemical content reporting requirements for soil amendments, composts and fertilizers. The Maximum Allowed Thresholds (MAT) indicates toxicant levels above which the material would not be considered acceptable

Table 2: Test Category B Characteristics and Criteria (Basic Biochar Toxin Reporting - required for all feedstocks)

Parameter	Range of Maximum Allowed Thresholds	Test Method
Earthworm Avoidance Test	Pass/Fail	ISO 17512-1:2008 methodology and OECD methodology as described by Van Zwieten et al.(2010).;
Germination Inhibition Assay	Pass/Fail	OECD methodology as described by Van Zwieten et al. (2010).
Polycyclic Aromatic	6 -20	Protection Agency (1996)

Parameter	Range of Maximum Allowed Thresholds	Test Method
Hydrocarbons (PAH)	6 -20	mg/kg TM Protection Agency (1996)
Furan	0.5	ng/kg I-TEQ US Environmental Protection Agency (2007)
Dioxin	0.5	ng/kg I-TEQ

Test Category C and D

Advanced Analysis and Soil Enhancement Properties Test Category C and D are optional for all biochar materials. Manufacturers may report on none, one, some, or all of the properties contained in the Test Category C (table 3) and D (table 4) set of advanced analysis and soil enhancement properties, using the prescribed test methods.

Table 3: Test Category C Characteristics and Criteria (US Composting Council and US Department of Agriculture 2001)

Parameter	Range of Maximum Allowed Thresholds (mg/kg)
Polychlorinated Biphenyls (PCB) Method following US Environment Protection Agency (1996)	0.2 -0.5
Arsenic	12 -100
Cadmium	1.4 - 39
Chromium	64 -100
Cobalt	100 -150
Lead	70 -500
Molybdenum	5 -75
Mercury	1 -17
Nickel	47 -600
Selenium	1 -100



Parameter	Range of Maximum Allowed Thresholds (mg/kg)
Zinc	200 -2800
Boron	Declaration
Chlorine	Declaration
Sodium	Declaration

Table 4: Test Category D Characteristics and Criteria

Parameter	Criteria	Unit	Test Method
Mineral N (ammonium and nitrate)	Declaration	mg/kg	2M KCl extraction, following by spectrophotometry (Rayment and Higginson 1992)
Total Phosphorus & Potassium (P&K)*	Declaration	% content	Modified dry ashing followed by ICP (Enders and Lehmann 2011)
Available P	Declaration	mg/kg	2% formic acid followed by spectrophotometry (modified from Rajan et al. 1992)
Electrical Conductivity	Declaration	dS/m	EC analysis procedure as outlined in section 04:10 of US Composting Council and US Department of Agriculture (2001), following dilution and sample equilibration methods from Rajkovich et al. (2011).
Porosity	Declaration	cm ³ /g	ASTM D 6556 -10 Standard Test Method for Carbon Black - Total and External Surface Area by Nitrogen Adsorption
Surface Area	Declaration	m ² /g	

* Total K is sufficiently equivalent to available K for the purpose of this characterization

Product Labeling Instructions *(Adapted from IBI)*

Product labeling is an important aspect of any certified biochar product. To qualify for a certified product, biochar producers/manufacturers must reveal about the feedstock used and final characteristics of biochar material developed. This information is important to the biochar users and regulators. Along with labeling there is need to guide the end user about its storage, use and transportation of biochar in compliance with Hazardous Materials Identification System.

Application Rate, Methods and Frequency

The biochar has a great potential towards improving crop production and climate change mitigation. For improvement in the soil fertility biochar should ideally be applied near the soil surface in the root zone where the bulk of nutrient cycling and uptake by plants takes place. If biochar is to be applied solely for the purpose of carbon sequestration in soil, it should be placed deeper in the soil. For agriculture purpose, while deciding how to apply biochar to soil, the specific cropping system must be taken into consideration. Biochar has potential to facilitate the establishment of vegetation on degraded soils and soils contaminated with heavy metals, organic compounds, and pesticides. It can also be used for degraded area reclamation (Jha et al., 2016). Biochar could be used to trap nutrients or other pollutants in strips near waterways, or even directly inside streams or at outlet of drainage ditches. Apart from field and horticultural crops biochar could be applied in layers below the rooting zone of grass to serve as barrier for leached nutrients and pesticides. Suitable methods and size of biochar may be selected for the same. It also helps in moisture retention. Even biochar can be applied in trenches radiating out from the base of established trees or pits dug for planting.

The application of biochar to crops in different soils and crops has revealed that it may be applied at rate varying between 5-20 t/ha. However, it all depends upon many factors such as amount of biochar available, soil type, crop, cropping sequence etc. Application of biochar even to the tune of 50 t/ha have been attempted by the researchers but sometime may be unaffordable and uneconomic. More data on appropriate application rates for any planting area, treatment and planning for pit application is needed. The majority of biochar field studies have suggested for broadcasting and incorporation in soil. Biochar could be mixed with sand, topsoil, compost prior to application to soil. In horticultural and widely spaced crops banding of biochar has been advocated to be the best option. Also, biochar can be added to planting pits at the time of new plantation. After plantation it could be applied as surface and sub-surface banding or top dressed over perennial vegetation in orchards. Nursery seedlings grown in biochar containing medium and transplanted in the field could benefit from biochar early. Lower amount of biochar is needed for band placement than the broadcast application. In addition to this, mixing of biochar with other soil amendments such as FYM, compost, slurry, vermicompost, lime etc. may further improve the efficiency of biochar.

The biochar application to soil as an agricultural practice will fail to gain traction unless viable application methods are developed. Moistened biochar material may be preferred



over dry broadcasting. Due to its recalcitrance to decomposition in soil, single application of biochar may provide beneficial effect over several growing seasons in the field (Steiner et al., 2007; Major et al., 2010). Farmers and gardeners around the world are actively exploring the use of biochar in a variety of field and green house settings. Data collection and documentation of these efforts is needed to determine the actual spread and impact of biochar management practices.

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Notes

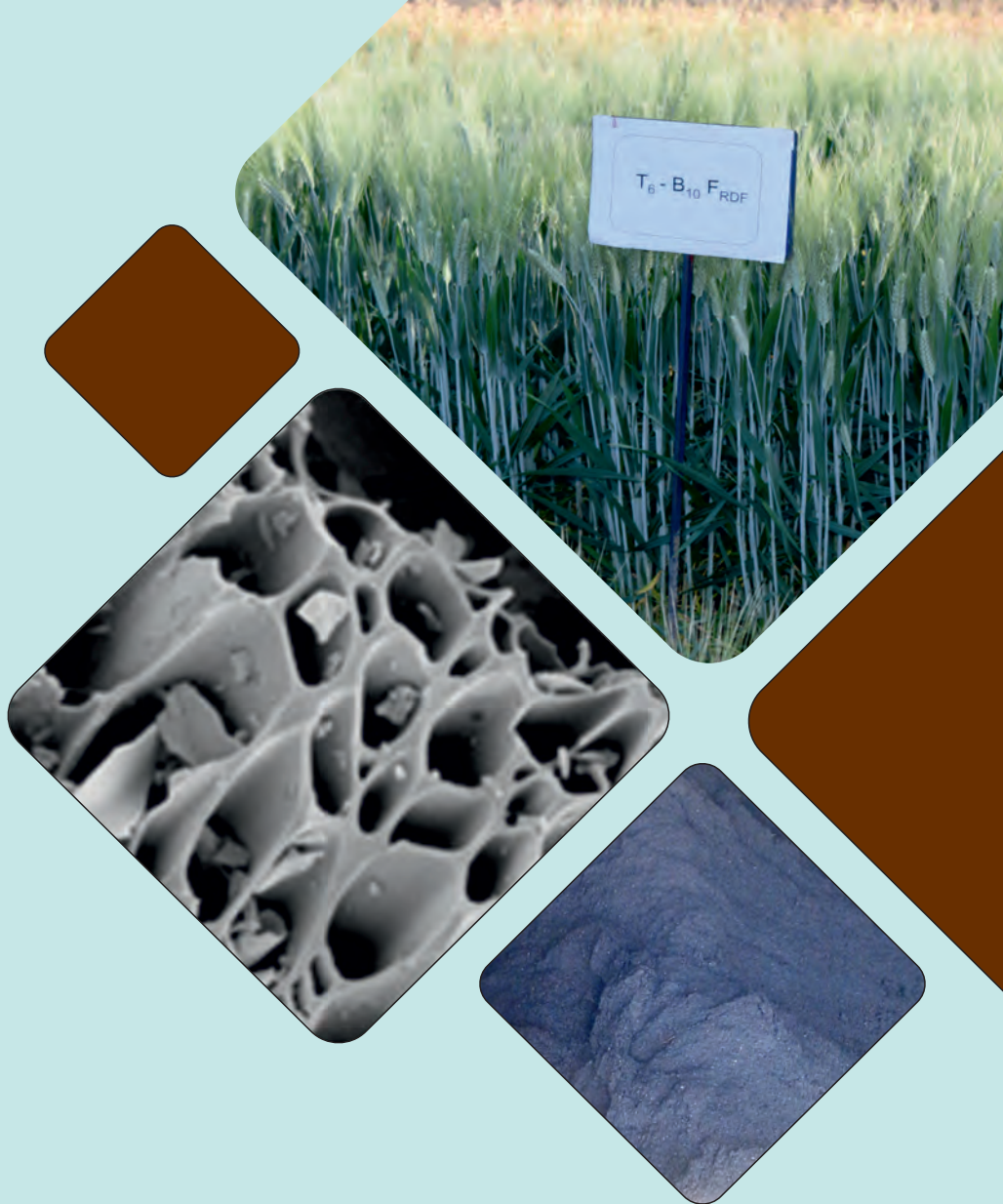
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